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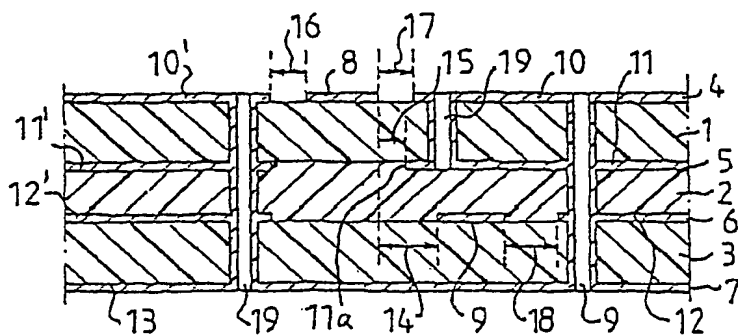
(57) Abstract: The invention relates to a directional coupler comprising coupled lines, and a method for achieving coupling in a directional coupler under compensation conditions. The directional coupler comprises coupled lines (8, 9), including a first line (8) and a second line (9), and at least one ground plane (10, 11, 13). At least one of the ground planes is a tuning ground plane (10, 11, 13), and a distance (14, 25), between the first (8) and the second (9) line, and each distance (15, 17, 26, 27), be-tween the first line (8) and the respective tuning ground plane (10, 11, 13), are adapted so as to contribute to a desired coupling level under compensation conditions.

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AN IMPROVED DIRECTIONAL COUPLER

TECHNICAL FIELD

5   The present invention relates to a directional coupler comprising coupled lines, and a method for achieving coupling in a directional coupler under compensation conditions.

BACKGROUND

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A directional coupler is a well known four port element for radio frequency equipment. This device allows a sample of a radio or microwave frequency signal, which is provided to an input port and received at an output port, to be extracted from the input signal. Properly designed, the directional coupler can distinguish between a

15   signal provided to the input port and a signal provided to the output port. This characteristic is of particular use in a radio frequency transmitter in which both the transmitted signal and a signal reflected from a mismatched antenna can be independently monitored. To obtain such performance, directivity of the coupler should be very high. Directivity of the coupler is high if so called "compensation condi-

20   tions" are fulfilled. There are two compensation conditions, assuming validity of quasi-static approximation: 1) the capacitive and inductive coupling coefficients are equal, and 2) the coupler is terminated with the proper impedances (preferably 50 Ohms) – for more details see for instance: K. Sachse, A. Sawicki, Quasi-ideal multilayer two- and three-strip directional couplers for monolithic and hybrid MICs,

25   IEEE Trans. MTT, vol. 47, No. 9, Sept. 1999, pp. 1873 – 1882.

Directional couplers intended to be used as monitors of transmitted power or power reflected from an antenna should have weak couplings (coupling of -30 to -40 dB) and high directivity (at least 20 dB). It is a very known property of directional cou-

30   plers that directivity is lower for weakly coupled lines than for tightly coupled ones.

Therefore, couplers having a weak coupling are difficult to make so that they are compensated. The article mentioned above by K. Sachse and A. Sawicki describes couplers that are suitable for tight couplings, in the region of –3 dB to –8 dB, corresponding to coupling levels of 0.7 to 0.4. However, weak couplings under compen-

5   sation conditions can not be obtained with the configurations in the article.

A good solution for these types of couplers is utilizing pure strip line configuration with homogeneous dielectric media. Unfortunately, this solution can be applied only for the couplers built as separate components. They can not, or can hardly be applied

10   in an integrated circuit environment where transmission lines carrying a power signal are integrated mainly on the top surface of, or placed beside a multilayer printed board.

Directional couplers formed in coplanar or conductor-backed coplanar and quasi-

15   strip line configurations are described in the US 4,288,760 patent, and here presented in fig. 1 and fig. 2, respectively. It can be seen that in both configurations the coupled lines are located at a vertical distance from each other, and also at a horizontal distance from each other. Compensation of these couplers is achievable at only one mutual position of coupled strips, and the corresponding coupling is at a

20   dozen or so dB level. In these couplers, if compensation conditions are to be kept, only a small reduction of coupling is possible by increasing the height of the dielectric layer separating the coupled strips. Moreover, the configuration shown in fig. 1 is not convenient for multilayer boards, because positions of the external ground planes, e.g. formed by a mechanical construction, are very critical for parameters of

25   the coupler, and small alterations of external ground plane positions will cause large deviations of the coupler parameters.

Directional couplers formed in coaxial line – microstrip printed line configurations are described in the US 5,926,076 and EP 228265 publications. In both configura-

30   tions the outer conductor of the coaxial line has a longitudinal opening, allowing

coupling to a microstrip line etched on a printed circuit board and placed beside the opening. The coupling level can be adjusted in these configurations changing the horizontal distance between the inner conductor of the coaxial line and the micro-strip line. However, nothing is mentioned in these publications about whether the couplers are compensated, or how to compensate them.

SUMMARY

It is an object of the invention to present a directional coupler that can assure a wide range of weak couplings realised under compensation conditions.

The object is reached with a directional coupler comprising coupled lines, including a first line and a second line, and at least one ground plane, characterised in that at least one of the ground planes is a tuning ground plane, and in that a distance, be-tween the first and the second line, and each distance, between the first line and the respective tuning ground plane, are adapted so as to contribute to a desired coupling level under compensation conditions.

The possibility of adjusting the distance between the tuning ground plane(s) and the first line, contributes substantially to possibilities of adjusting the coupling level and compensating the coupler. In turn, this makes possible to obtain high directivity of the coupler.

The inventions makes it possible to adjust the relationship between the distance, between the first and the second line, and each distance, between the first line and the respective tuning ground plane, so as to contribute to a desired coupling level under compensation conditions. More in particular, adjusting the distance between the tuning ground plane(s) and the first line also changes the coupling level. So, the coupling level and obtaining the compensation condition should be tuned in parallel.

Preferably, the width of the first and/or the second line are adapted so as to contribute to a desired coupling level under compensation conditions. This means that said parameters also could be adjusted to reach compensation conditions. More specifically, widths of the first and the second lines can be adjusted to match the first and the second line to desired impedance, preferably 50 ohms.

In principle, four parameters can be adjusted, namely (i) the distance between the first and the second line, (ii) the distance between the tuning ground plane(s) and the first line, (iii) the width of the first line, and (iv) the width of the second line, in order to obtain (i) equalisation of capacitive and inductive coupling coefficients, and suitable values of (ii) the coupling level, (iii) impedance of the first line, and (iv) impedance of the second line.

Preferably, the second line and the respective edge of the at least one ground plane are located on the same side of the first line. This will facilitate compensating the coupler by adjusting the distance between the respective edge of the at least one ground plane and the first line.

Preferably, the directional coupler comprises at least two conductive layers, whereby at least one dielectric layer is interposed between the conductive layers. Thereby, the coupler configuration is convenient to be manufactured in a standard multilayer printed circuit board technology. In other words, a directional coupler configured in multilayer printed circuit environment that can assure a wide range of weak couplings realized under compensation conditions is presented.

Preferably, an electrical length of the directional coupler is a quarter or less of the wavelength.

Preferably, the first line comprises at least two strips separated in a vertical direction and electrically joined by means of at least one connection. Thereby, it is possible to

obtain the line with a low insertion loss and that can carry a high power of a trans-
mitted signal. Additionally, where dielectric material is used to separate the strips,
and the former is milled out so that a so-called quasi-air line is created, almost no
dielectric losses occur in the former, since the conductive layers, or strips, have the
same electrical potential, and the electromagnetic field doesn't penetrate the dielec-
tric material.

Preferably, a region between the first and the second lines comprises at least partly a
gas, and at least one dielectric layer is arranged between the second line and the at
least one tuning ground plane, whereby each distance between the first line and the
respective tuning ground plane is dependent on the respective distance between each
tuning ground plane and a boundary between the gas and the dielectric layer. The
first line can be surrounded completely by the gas, and the second line can be
imbedded in at least one dielectric material, or the second line can be in partial con-
tact with the gas and partial contact with the dielectric material. Thereby, the power
handling capability of the first line is further increased.

The object is also reached with a method for achieving coupling in a directional
coupler under compensated conditions, the coupler comprising coupled lines in-
cluding a first and a second line, and at least one ground plane, characterised in that
it comprises choosing a distance, between the first and the second line, and each
distance, between the first line and an edge of at least one of the ground planes, so
as to contribute to a desired coupling level under compensation conditions.

This method is very useful when designing a directional coupler, or when adjusting
an existing coupler or coupler design, in order to achieve a wide range of weak cou-
plings realised under compensation conditions.

BRIEF DESCRIPTION OF DRAWINGS

Below, the invention will be described in detail with reference to the drawings, in which

5   - fig. 1 and 2 show sectional views of coupled lines directional couplers according to known art, sectioned perpendicular to the coupled lines,

- fig. 3 shows a sectional view of a coupled lines directional coupler according to a first embodiment of the invention, sectioned perpendicular to the coupled lines,

- fig. 4 shows a diagram with coupling coefficients for the directional coupler

10   shown in fig. 3,

- fig. 4a shows a cross-section corresponding to the one in fig. 3 to explain variables in the diagram of fig. 4,

- fig. 5 shows a sectional view of a coupled lines directional coupler according to a second embodiment of the invention, sectioned perpendicular to the coupled

15   lines,

- fig. 6 shows a diagram with coupling coefficients for the directional coupler shown in fig. 5,

- fig. 6a shows a cross-section corresponding to the one in fig. 5 to explain variables in the diagram of fig. 6,

20   - fig. 7 shows a sectional view of a coupled lines directional coupler according to a further embodiment of the invention, sectioned perpendicular to the coupled lines,

- fig. 8 shows a diagram with effective dielectric constants calculated for two orthogonal modes propagated in the coupled lines in the configuration shown in

25   fig. 7,

- fig. 8a shows a cross-section corresponding to the one in fig. 7 to explain variables in the diagram of fig. 8,

- fig. 9-13 show sectional views of coupled lines directional couplers according to additional embodiments of the invention, sectioned perpendicular to the coupled

30   lines,

- fig. 14a shows a diagram with effective dielectric constants calculated for two orthogonal modes propagated in the coupled lines in the configuration shown in fig. 13,

- fig. 14b shows a diagram with coupling coefficients for the directional coupler shown in fig. 13,

- fig. 14c shows a cross-section similar to the one in fig. 13 to explain variables in the diagram of fig. 14a and 14b, and

- fig. 15 shows a sectional view of a coupled lines directional coupler according to a further embodiment of the invention, sectioned perpendicular to the coupled lines.

DETAILED DESCRIPTION

In Fig. 3, cross-section of a structure of a coupled lines directional coupler according to a first embodiment of the invention is presented. Like other embodiments of the invention, it is suitable for multilayer printed circuit technologies and weak couplings. It comprises a first 1, a second 2 and a third 3 dielectric layer in the form of substrates. The first dielectric layer 1 is located above the second dielectric layer 2, and the second dielectric layer 2 is located above the third dielectric layer 3. The coupler comprises a first 4, a second 5, a third 6 and a fourth 7 conductive layer. The first conductive layer 4 is located on top of the first dielectric layer 1. The second conductive layer 5 is located between the first dielectric layer 1 and the second dielectric layer 2. The third conductive layer 6 is located between the second dielectric layer 2 and the third dielectric layer 3. The fourth conductive layer 7 is located below the third dielectric layer 3.

Coupled lines 8, 9, in the form of strips, preferably straight and parallel, and having a longitudinal axis, here referred to as a first 8 and a second 9 line, are formed in the first 4 and the third 6 conductive layer, respectively. In the description of embodiments of this invention, the first line 8 is also referred to as a main line.

In any embodiment of the invention, the first and second lines could also be arranged so that the distance between them varies, for example in a case where one of them, or both, are tapered or curved, or in a case where they are straight but non-

5   parallel. For this presentation, the longitudinal axis of the coupled lines is defined as the longitudinal direction of the mass distribution of both lines. In a case where the coupled lines are straight and parallel, the longitudinal axis of the coupled lines is parallel to each of them.

10   The first and the second line 8, 9 are located at a horizontal distance 14 from each other. In this embodiment, since the first and the second line 8, 9 are formed in separate conductive layers, they are also located at a vertical distance from each other, which is approximately equal to the sum of the thicknesses of the first 1 and the second 2 dielectric layer.

15

In the first 4, second 5, third 6 and fourth 7 conductive layer, a respective first 10, 10', second 11, 11', third 12, 12' and fourth 13 ground plane are formed. The fourth ground plane 13 is also referred to as a lower ground plane 13. The first 10, 10', second 11, 11', and third 12, 12' ground plane each include a first region 10, 11, 12,

20   and a second region, 10', 11', 12', which are, in a direction parallel to the ground planes and perpendicular to the longitudinal direction of the coupled lines 8, 9, located on opposite sides of the first line 8.

The second regions of the first, second and third ground plane 10', 11', 12', located

25   on the same side of the first line 8, are preferably located at the same horizontal distance 16 from the first line 8. This will be practical, since it will facilitate the introduction of a plurality of connections 19, or via holes 19, connecting the second regions 10', 11', 12' and the lower ground plane 13, the via-holes being located along a line parallel to the coupled lines 8 and 9. However, as an alternative, the

second regions of the first, second and third ground plane 10', 11', 12' could be located at un-equal horizontal distances from the first line 8.

The horizontal distance 16 between the second regions 10', 11', 12' of the first, second and third ground planes and the first line 8 can be adjusted to achieve the desired impedance of the first line.

The first region of the second ground plane 12, which is located on the same side of the first line 8 as the first region of the second ground plane 11, is located at a distance 18 from the second line 9. The first region of the first 10, second 11, and third 12 ground plane and the lower ground plane 13 are connected by means of a plurality of via holes 19 placed along a line parallel to the coupled lines 8 and 9.

The first region of the second ground plane 11, which is, in a direction parallel to the ground planes and perpendicular to the longitudinal direction of the coupled lines 8, 9, located on the same side of the first line 8 as the second line 9, is here referred to as a tuning ground plane 11.

As can be seen in fig. 3, the tuning ground plane 11 is, in a direction perpendicular to the ground planes, located between the first 8 and the second line 9. The first line 8 and the tuning ground plane 11, formed in separate conductive layers, are located at a vertical distance from each other, which is approximately equal to the thickness of the first dielectric layer 1.

As described further below with reference to fig. 4 and 4a, a horizontal distance 15 between the first line 8 and an edge 11a of the tuning ground plane 11 is adjusted to achieve compensation conditions for a wide range of weak couplings.

The first region 10 of the first ground plane is placed at the same distance 17 from the first line 8 as the second region 10'. However, as an alternative, the distances 16,

17 between the first region 10 of the first ground plane and the first line 8, and the

second region 10' of the first ground plane and the first line 8 could be un-equal. In

fact, the first region 10 of the first ground plane could be used a supplementary

tuning ground plane, whereby the distance 17 between the edge of the first region 10

5   of the first ground plane and the first line 8 could be adjusted along with the dis-

tance 15 between the first region 11 of the second ground plane and the first line 8

to achieve compensation conditions for a wide range of weak couplings.

Fig. 4 shows results of calculations of the coupling coefficients of the coupler de-

10   scribed above, as a function of the horizontal distance 15 between the first line 8

and the tuning ground plane 11 (fig. 3), and the horizontal distance 14 between the

first 8 and the second 9 line as a parameter. The permittivity of the dielectric layers

is referred to as eps1, eps2, and eps3. eps1 and eps3 values are typical for a core

material, and eps2 value is typical for a prepreg material. kc and kl refer to the ca-

15   pacitive and inductive coupling coefficients, respectively. The directional coupler is

compensated if these two coefficients are equal and the ports of the coupler are ter-

minated, in this case with 50 Ohms impedance. It can be seen in fig. 4 that the con-

figuration assures wide range of weak couplings, i.e. from -20 dB to -37 dB and be-

yond, while being compensated. To clarify that these are weak coupling levels, it is

20   pointed out that –20 dB correspond to a ratio between the power transferred to the

second line 9 and the total power propagated in the main line 8 of 0.01, and –30 dB

correspond to a ratio between the power transferred to the second line 9 and the total

power propagated in the main line 8 of 0.001. The ground plane 11 has a central

function in adjusting the coupling level and to compensate the coupler. The cou-

25   pling level can be adjusted by changing the distance 14 between the first line 8 and

the second line 9 and adjusting the distance 15 between the first line 8 and the tun-

ing ground plane 11. The adjustment of the distance 15 between the first line 8 and

the tuning ground plane 11 will also tune the coupler to the compensation condi-

tions. At the same time width of the first line 8 and the second line 9 should be ad-

30   justed to fulfil the matching condition of the compensation conditions. These widths

vary from 120 to 126 mils for the line 8 and from 21 to 31 mils for the line 9 when the first 14 and the second 15 horizontal distances vary over the range shown in fig. 4.

5   Fig. 5 shows a directional coupler according to a second embodiment of the invention. The physical configuration of the second embodiment is similar to the first embodiment described with reference to fig. 3, except for the following. Differing from the first embodiment, the second line 9 is formed in the second conductive layer 5. Thus, in this embodiment, the vertical distance between the coupled lines is ap-

10   proximately equal to the thickness of the first dielectric layer 1. Further, differing from the denotation used with reference to fig. 3, in the third conductive layer 6 a second ground plane 11, 11' is formed, and in the second conductive layer 5 a third ground plane 12, 12' is formed. The second line 9 is, in a direction perpendicular to the ground planes, located between the first line 8 and the first region of the second

15   ground plane 11. The vertical distance between the first line 8 and the first region of the second ground plane 11 is approximately equal to the sum of the thicknesses of the first 1 and the second 2 dielectric layer.

The first region 10 of the first ground plane and the first region of the second

20   ground plane 11 are referred to as tuning ground planes and are both, in a direction parallel to the ground planes and perpendicular to the longitudinal direction of the coupled lines 8, 9, located on the same side of the first line 8 as the second line 9. Also, the first line 8 and tuning ground plane 11 are located at a horizontal distance 15 from each other, and the first line 8 and tuning ground plane 10 are located at a

25   horizontal distance 17 from each other. Thus, in this embodiment, the coupler is tuned for compensation by adjusting the horizontal distances 17, 15 between first line 8 and an edge 10a of the first region 10 of the first ground plane and an edge 11a of the first region 11 of the second ground plane, respectively.

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As an alternative, only the distance 15 can be adjusted for compensation, whereby the first 10 and the second 10' region of the first ground plane could be placed with preferable equal distances 16, 17 from the first line 8.

5   Fig. 6 shows results of calculations of the coupling coefficients, of the coupler described with reference to fig. 5, as a function of the horizontal distances 15, 17 (s) (see fig. 6a) between the first line 8 and the tuning ground planes 10, 11, and the horizontal distance 14 between the first 8 and the second 9 line as a parameter (s1). Thus, in fig. 6 the results are obtained by setting the horizontal distance 17 (see fig.
10   5) between the first line 8 and the tuning ground plane 10 equal to the horizontal distance 15 between the first line 8 and the tuning ground plane 11.

It can be seen in fig. 6 that with the coupler according to the second embodiment essentially the same wide range of weak couplings is achievable while the coupler is
15   compensated, as with the coupler according to the first embodiment. Accompanying widths of the first line 8 and the second line 9, assuring the matching to 50 Ohms condition, vary from 104 to 130 mils and from 21 to 40 mils, respectively.

In the first and second embodiments, presented with reference to fig. 3 and 5, re-
20   spectively, the configurations utilized the conductor-backed coplanar line 8 on the first conductive layer 4 and quasi strip line 9 on the third 6 or on the second 5 conductive layer.

Fig. 7 shows a further embodiment, in the form of a microstrip – quasi strip line
25   configuration, whereby positions of a first line 8, a second line 9 and a tuning ground plane 11 correspond to the positions of the respective corresponding elements in the configuration shown in fig. 3. A lower ground plane 13 is present below the second line 9. The embodiment shown in fig. 7 differs from the embodiment shown in fig. 3 in that, at least in a vicinity of the coupled lines 8, 9, there are no
30   ground planes at conductive layers in which the first line 8 and the second line 9 are

formed. Also, a part corresponding to the second region 11' of the second ground

plane in the embodiment shown in fig. 3 is not present in the embodiment shown in

fig. 7. In the embodiment in fig. 7, the first line 8 and the lower ground plane 13

form a microstripline configuration, in which the first line 8 is a microstripline 8,

5   and the second line 9, the tuning ground plane 11 and the lower ground plane 13

form a stripline configuration, in which the second line 9 is a quasi strip line 9.

Surprisingly, it has been found that weak couplings at compensation conditions can

be obtained with a big difference in propagation velocities of two orthogonal modes

10   propagated in the coupled lines. This is illustrated in fig. 8 and 8a, in which effec-

tive dielectric constants calculated for two orthogonal modes propagated in the cou-

pled lines in configuration shown in fig. 7, and a cross-section corresponding to the

one in fig. 7 to explain variables in the diagram, are presented. Dielectric permittiv-

ity of the dielectric layers is chosen to be the same for each layer, and equal to 3.6.

15   In fig. 8, eps eff c corresponds to the wave propagated in the stripline 9. Notice, that

if the stripline 9 is covered with the tuning ground plane 11, which corresponds to

small values of s, effective dielectric constant for this mode is equal to the dielectric

permittivity of the dielectric layers, as it should be for the stripline 9. eps eff pi cor-

responds to the wave propagated in the microstripline 8 and differs very much from

20   eps eff c.

Further modifications of the configurations described above are possible within the

scope of the present invention. On the side of the first line 8 opposite to the side

where the second line 9 and the tuning ground plane 11 are positioned, any ar-

25   rangement of the ground planes 10', 11' and 12' is possible. Thereby, only some of

the latter can be present, or all of them can be omitted. The ground planes positioned

at the vicinity of the first 8 or the second line 9 can be useful for tuning these lines

to the terminating impedance (50 Ohms) at convenient geometrical dimensions.

Fig. 9 shows an alternative configuration in which positions of a first line 8, a second line 9 and a tuning ground plane 11 corresponds to the positions of the respective corresponding elements in the configuration shown in fig. 7. Additionally, a second ground plane region 11' formed in the same conductive layer as the tuning ground plane is presented, in a horizontal direction, on the opposite side of the first line 8. Also, in a horizontal direction, on the same side of the first line 8 as the tuning ground plane 11, a first ground plane 10 is formed on the same conductive layer as the first line 8, and located at a distance 17 from the latter. The first ground plane 10 can be used as a supplementary tuning ground plane, whereby compensation conditions for a wide variety of weak couplings can be achieved by suitable adjustment of the horizontal distance 15 between an edge 11a of the tuning ground plane 11 and the first line 8, as well as the horizontal distance 17 between an edge 10a of the tuning ground plane 10 and the first line 8.

In the embodiments described above, the first line 8, whether in the form of a coplanar or a microstrip line, works in the coupler as a power carrying line. Fig. 10 shows an alternative embodiment, in which a first line is stacked, whereby an auxiliary line 20 on a second conductive layer 5 is located below a line 8 on a first conductive layer 4 and connected to the line 8 utilizing at least one, preferably a plurality of via holes 21 placed along the lines 8 and 20. This will extend the power handling capability of the line 8. Tuning ground planes 10 and 11 are supplied, whereby compensation conditions for a wide variety of weak couplings can be achieved by suitable adjustment of the horizontal distance 15 between the tuning ground plane 11 and the first line 8, as well as the horizontal distance 17 between the tuning ground plane 10 and the first line 8.

Preferably, an electrical length of the directional coupler, i.e. the distance on which the first and the second lines are coupled, is a quarter or less of length of the propagated wave – how to calculate this length for two modes propagated with different velocities see the above mentioned article: K. Sachse, A. Sawicki, Quasi-ideal mul-

tilayer two- and three-strip directional couplers for monolithic and hybrid MICs,
IEEE Trans. MTT, vol. 47, No. 9, Sept. 1999, pp. 1873 – 1882.

5   The configurations in fig. 3, 7, and 9 where the microstrip line 8 and the stripline 9
are, apart from being horizontally shifted, placed at a vertical distance from each
other, with the ground plane 11 separating these two propagation media, provide for
manufacturing couplers of high scale of integration, with a relatively small size,
which is a big advantage in many applications.

10   Fig. 11 shows an alternative embodiment in which dielectric material beside the first
line 8 is removed along the first line 8. The horizontal distances 16 and 17 indicate
the width of removed areas. Thereby, the region between the first and the second
lines 8, 9 comprises partly air. In general any suitable gas can be present in said re-
gion.

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The first line 8 is suspended over an external conductive chassis 23 at the vertical
distance 22. The external conductive chassis 23 is connected to the lower ground
plane 13. The first line 8 is composed of four printed lines placed on conductive
layers 4, 5, 6, and 7, and connected by means of plurality of via-holes 21 placed
20   along the first line 8. The coupling level between the first line 8 and the second line
9 depends mainly on the distance 25 between the lines, i.e. the sum of the distances
17 and 14. The first line 8 in this embodiment has low insertion loss and can carry
high power of a transmitted signal. There are almost no losses in the dielectric mate-
rial placed between conductive layers of the first line 8, because these conductive
25   layers have the same electrical potential.

Compensation of the directional coupler in the embodiment shown in Fig. 11 is pos-
sible due to tuning feature of tuning ground planes 10, 11, and 13, placed at a dis-
tance 15 from the edge of a dielectric material 1, 2, 3, surrounding the second line 9,
30   i.e. a distance 26 from the first line 8. In other words, by adjusting the distances 15

between the respective edge of each ground plane 10, 11, 13 and the boundary be-
tween the gas and the dielectric layers 1, 2, 3, compensation of the coupler can be
obtained. The distance 15 can be kept the same for each ground plane 10, 11, and
13, or can be different for each of these ground planes.

5

The directional coupler shown in cross sectional view in fig. 11 can be applied in
highly integrated modules where high power is transmitted through the first line 8,
whereby some parts of a circuit are placed on microstrip-type transmission medium
created by conductive layers 4 and 5, and other parts on strip-type transmission me-

10   dium created by conductive layers 5, 6, and 7. The length of a directional coupler
built in this configuration is shorter than the one built using air-filled transmission
medium, because effective dielectric constant of one of the modes propagated in the
structure is almost equal to the dielectric constant of the dielectric material 2 and 3,
surrounding the second line 9.

15

Another alternative embodiment of the invention presents a directional coupler
shown in a cross sectional view in fig. 12. This coupler is convenient for construc-
tion of stand-alone couplers. The only difference between this embodiment and the
one shown in fig. 11 is the lack of microstrip-type transmission medium. The quasi

20   air-filled first line 8 and strip-type second line 9 are used to compose the coupler.
Compensation of the coupler is possible by proper adjusting of horizontal distances
15, and 24, between the edges 11a, 13a of ground planes 11 and 13, and the edge of
a dielectric material surrounding the second line 9, i.e. the distances 26, 27 between
the ground planes 11, 13 and the first line 8. The distances 15 and 24 can be set

25   equal or different.

Because the first line 8 in the embodiments presented in fig. 11 and fig. 12 is quasi
air-filled, it is possible to replace the first multilayer printed line 8 by anyone sus-
pended in air-filled medium. fig. 13 shows yet another embodiment of the invention,

30   where a coaxial line inner conductor is applied as an exemplary air-filled first line 8.

Plenty of other cross section shapes of the first line 8 are allowed without affecting

the essential features of the directional coupler, e.g. square, rectangular or triangu-

lar. In fig. 13, a strip-type transmission medium is present, composed of the second

line 9 and ground planes 11 and 13. This embodiment can be supplemented by a mi-

5   crostrip-type transmission medium similar to the one shown in fig. 11, and com-

prising in fig. 11 the conductive layers 4 and 5.

Surprisingly it has been found that couplers built according to the embodiments pre-

sented in fig. 11, 12, and 13 can be compensated. The difference in propagation ve-

10   locities of two orthogonal modes propagated in the coupled lines is even larger in

said embodiments than in the embodiments presented with reference to fig. 3, 5, 7,

9, and 10. This is illustrated in fig. 14a-c in which inductive and capacitive coupling

coefficients kL, kC, and effective dielectric constants eps eff c, eps eff pi for two

orthogonal modes propagated in the coupled lines in the configuration similar to the

15   one shows in fig. 13, and a cross-section similar to the one in fig. 13 to explain vari-

ables in the diagrams, are presented. (Dissimilarities between the configurations in

fig. 13 and 14c are not essential.) Note that the coupler is compensated for s being

about 0.75 mm, where curves of coupling coefficients cross each other. Also, note

that effective dielectric constants of two modes are almost equal to the dielectric

20   constants of two different media surrounding the coupled transmission lines: 1 for

air surrounding the coaxial line, and eps for the dielectric of the strip line.

Yet another alternative embodiment is presented in fig. 15. This includes a simple

coaxial line - microstripline configuration. The coupler is compensated by proper

25   adjustment of the distance 24 between the ground plane 13 and the left vertical edge

of the dielectric layer 3.

Above, it has been mentioned that widths of the first and the second lines can be

adjusted to match the first and the second line to desired impedance, preferably 50

30   ohms. In addition to this, the distances between ground planes surrounding the lines

can be adjusted, to contribute to the matching of the first and the second line to 50 ohms.

CLAIMS

1. A directional coupler comprising coupled lines (8, 9), including a first line (8) and a second line (9), and at least one ground plane (10, 11, 13), characterised in that at least one of the ground planes is a tuning ground plane (10, 11, 13), and in that a distance (14, 25), between the first (8) and the second (9) line, and each distance (15, 17, 26, 27), between the first line (8) and the respective tuning ground plane (10, 11, 13), are adapted so as to contribute to a desired coupling level under compensation conditions.

2. A directional coupler according claim 1, wherein the width of the first and/or the second line (8, 9) are adapted so as to contribute to a desired coupling level under compensation conditions.

3. A directional coupler according to any of the preceding claims, wherein the distance (14, 25) between the first (8) and the second (9) line refers to a horizontal distance (14, 25) in a direction parallel to the at least one ground plane (10, 11, 13) and perpendicular to a longitudinal direction of the coupled lines (8, 9).

4. A directional coupler according to any of the preceding claims, wherein the second line (9) and the at least one tuning ground plane (10, 11, 13) are located on the same side of the first line (8).

5. A directional coupler according to any of the preceding claims, comprising at least two conductive layers (4, 5, 6, 7), whereby at least one dielectric layer (1, 2, 3) is interposed between the conductive layers.

6. A directional coupler according to any of the preceding claims, whereby an electrical length of the directional coupler is a quarter or less of length of the propagated wave.

7. A directional coupler according to any of the preceding claims, wherein the first
    line (8) comprises at least two strips separated in a vertical direction and electri-
    cally joined by means of at least one connection (21).

8. A directional coupler according to any of the preceding claims, characterised in
    that a region between the first and the second lines (8, 9) comprises at least
    partly a gas, and at least one dielectric layer (1, 2, 3) is arranged between the
    second line (9) and the at least one tuning ground plane (10, 11, 13), whereby
    each distance (26, 27) between the first line (8) and the respective tuning ground
    plane (10, 11, 13) is dependent on the respective distance (15, 24) between each
    tuning ground plane (10, 11, 13) and a boundary between the gas and the dielec-
    tric layer (1, 2, 3).

9. A method for achieving coupling in a directional coupler under compensated
    conditions, the coupler comprising coupled lined (8, 9), including a first (8) and
    a second (9) line, and at least one ground plane (10, 11, 13), characterised in that
    it comprises choosing a distance (14, 25), between the first (8) and the second
    (9) line, and each distance (26, 27), between the first line (8) and an edge of at
    least one of the ground planes (10, 11, 13), so as to contribute to a desired cou-
    pling level under compensation conditions.

10. A method according to claim 9, wherein the width of the first and/or the second
    line (8, 9) are chosen so as to contribute to a desired coupling level under com-
    pensation conditions.

11. A method according to claim 9 or 10, wherein the distance (14, 25) between the
    first (8) and the second (9) line refers to a horizontal distance (14, 25) in a direc-
    tion parallel to the at least one ground plane (10, 11, 13) and perpendicular to a
    longitudinal direction of the coupled lines (8, 9).

12. A method according to claim 9, 10, or 11, wherein the second line (9) and said respective edge of at least one of the ground planes (10, 11, 13) are positioned on the same side of the first line (8).

5
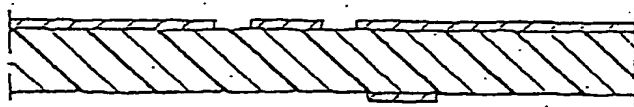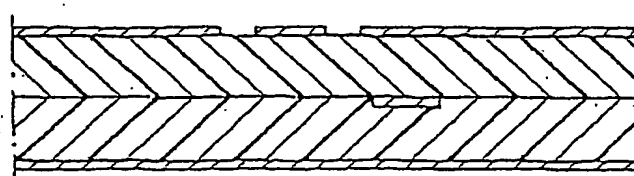
FIG.1

FIG.2
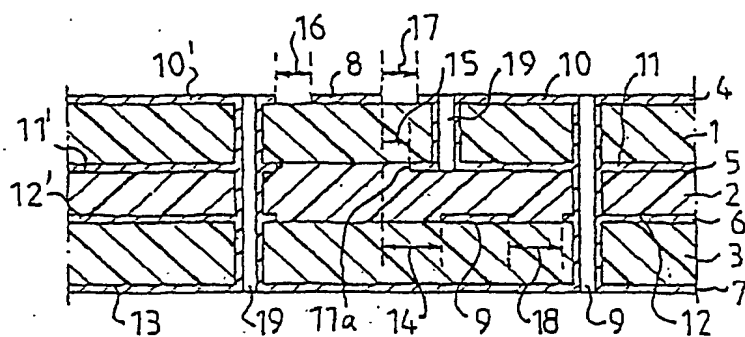
FIG.3

FIG.4a

FIG.4
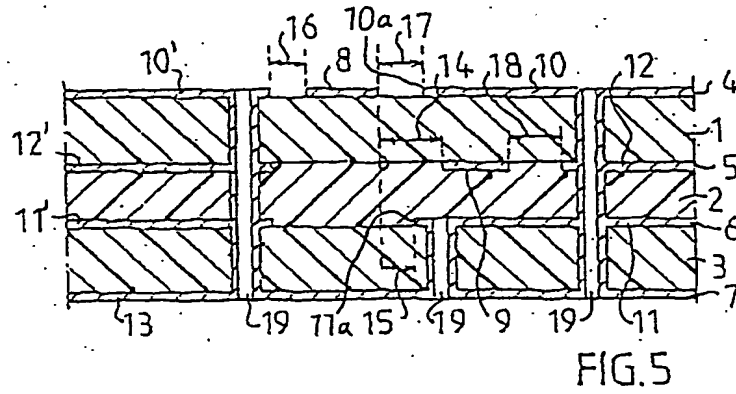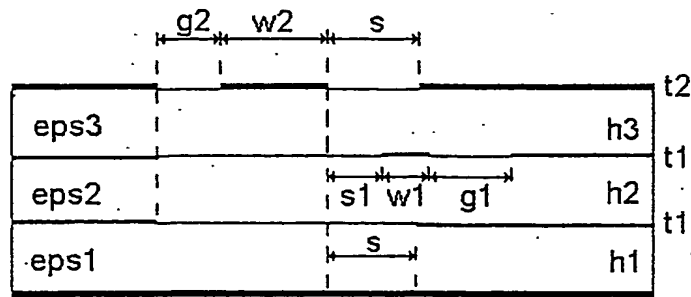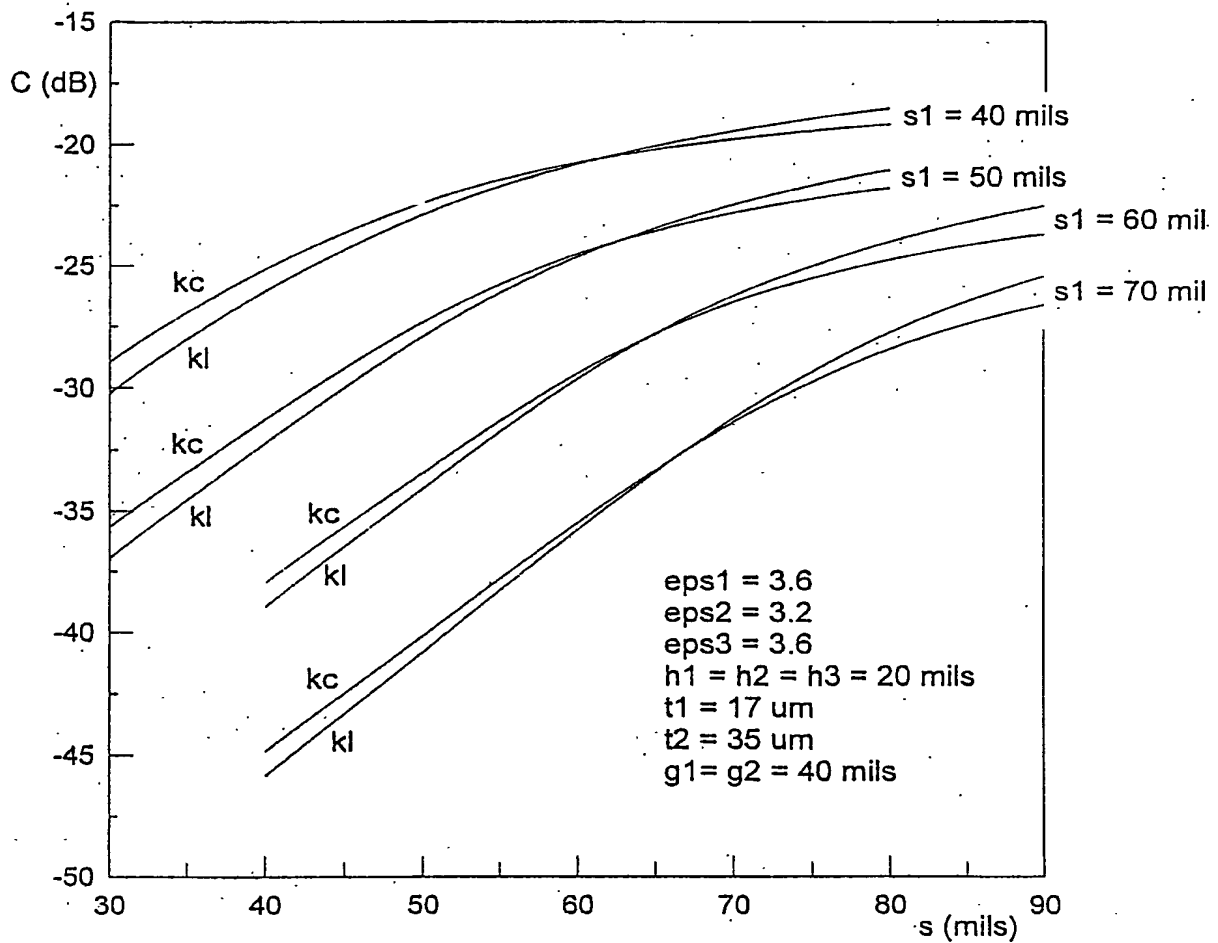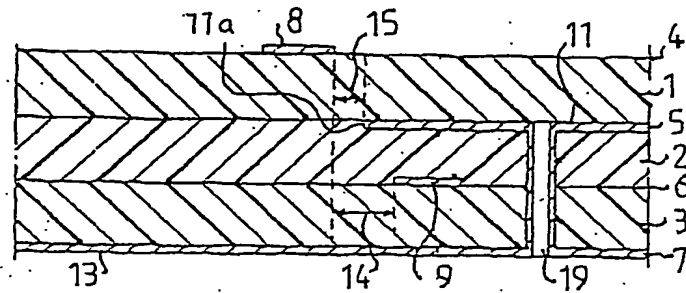
FIG.5
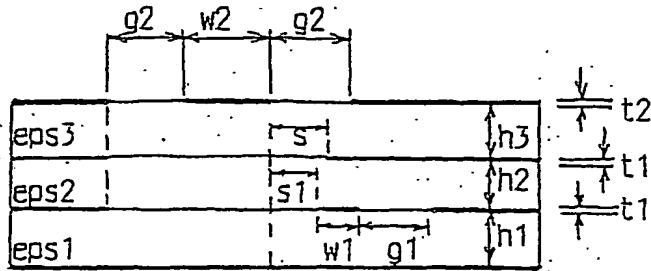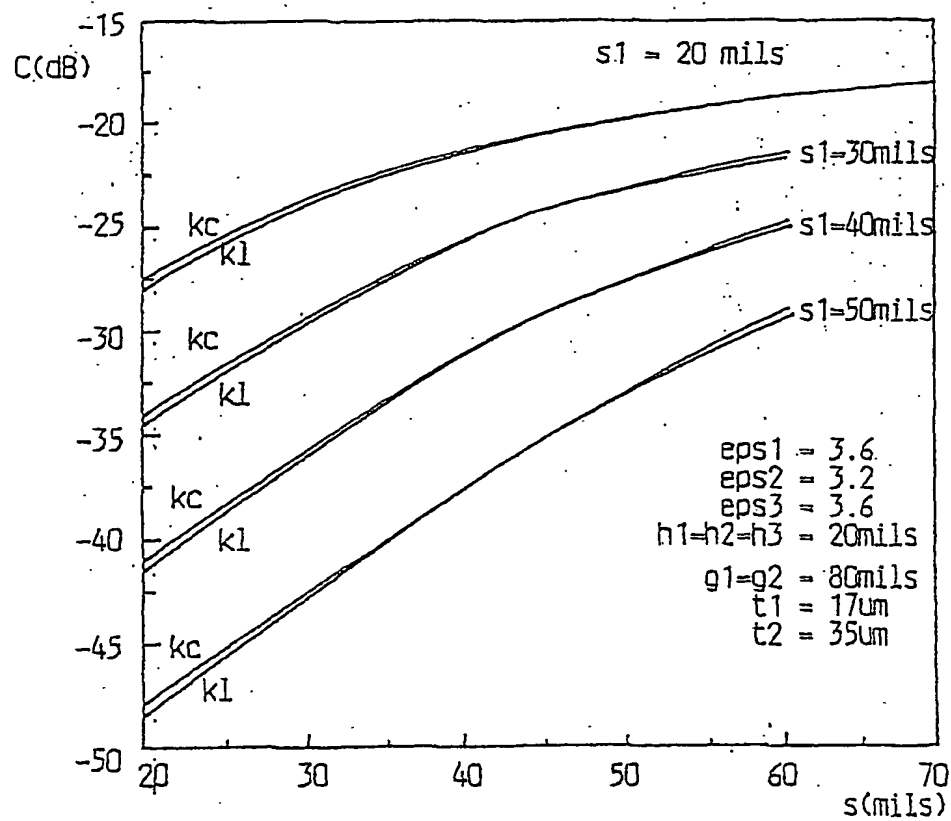
Fig. 6 a

Fig. 6

FIG. 7
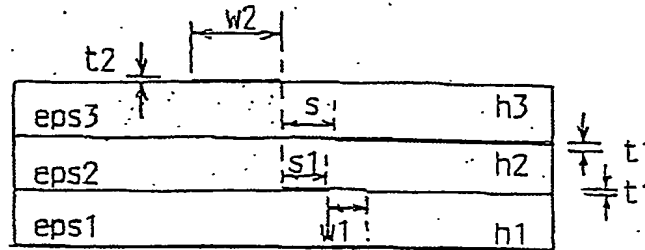
FIG. 9

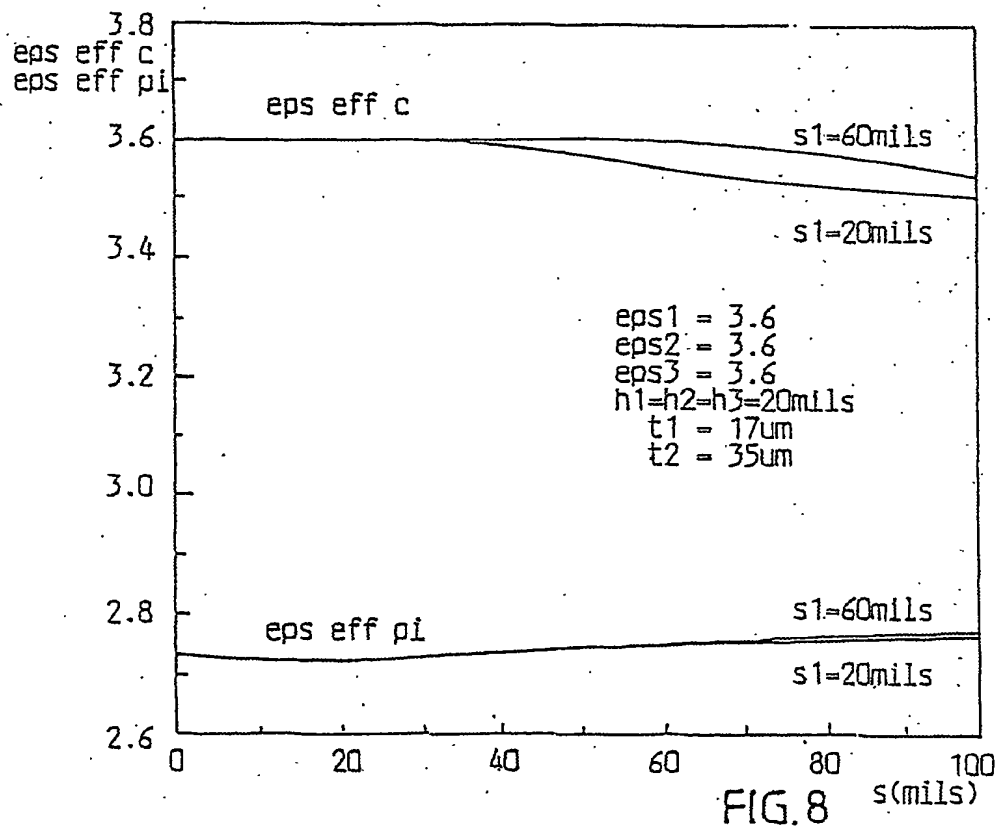FIG. 10

FIG. 8a
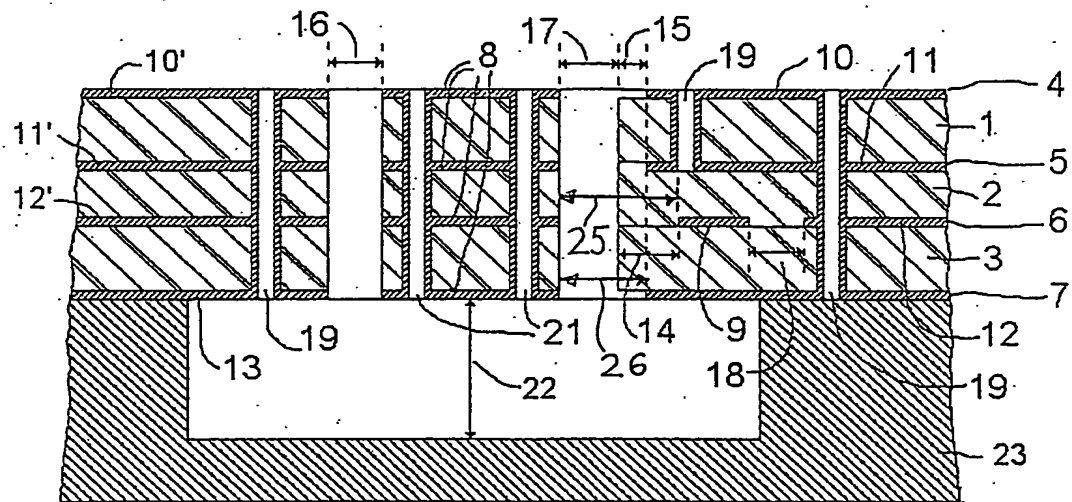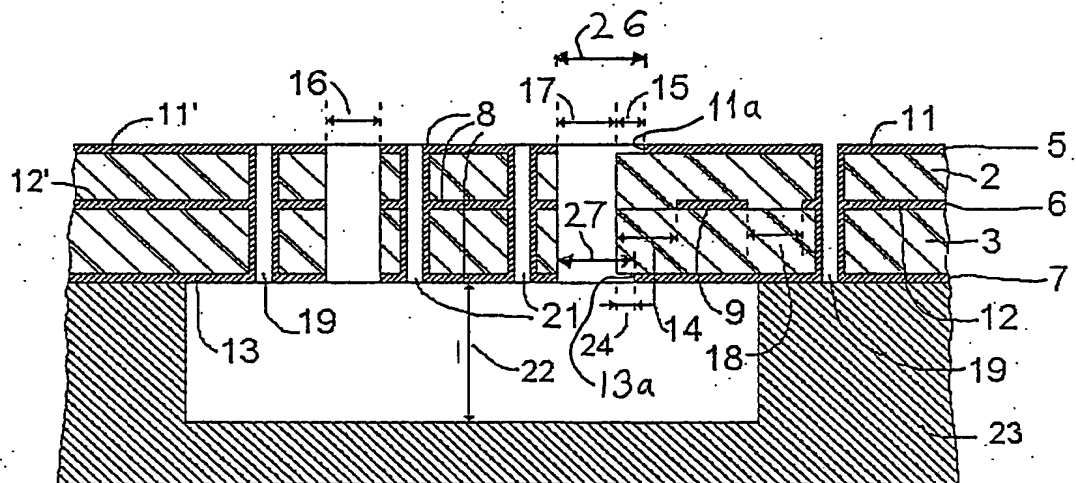

eps1 = 3.6
eps2 = 3.6
eps3 = 3.6
h1=h2=h3=20mils
t1 = 17um
t2 = 35um
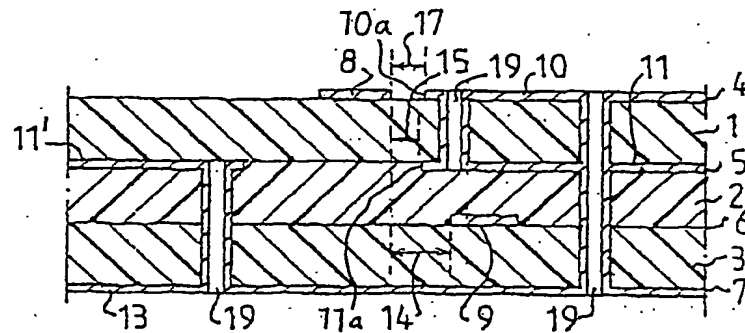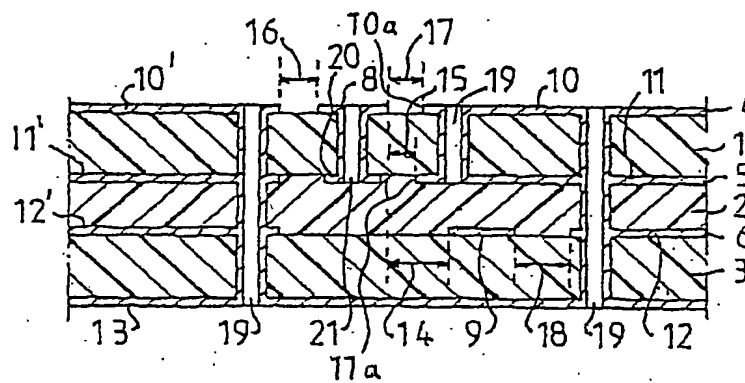
FIG.8   s(mils)

Fig. 11

Fig. 12

Fig. 13

Fig. 14 a

eps0 = 1
eps = 4.8
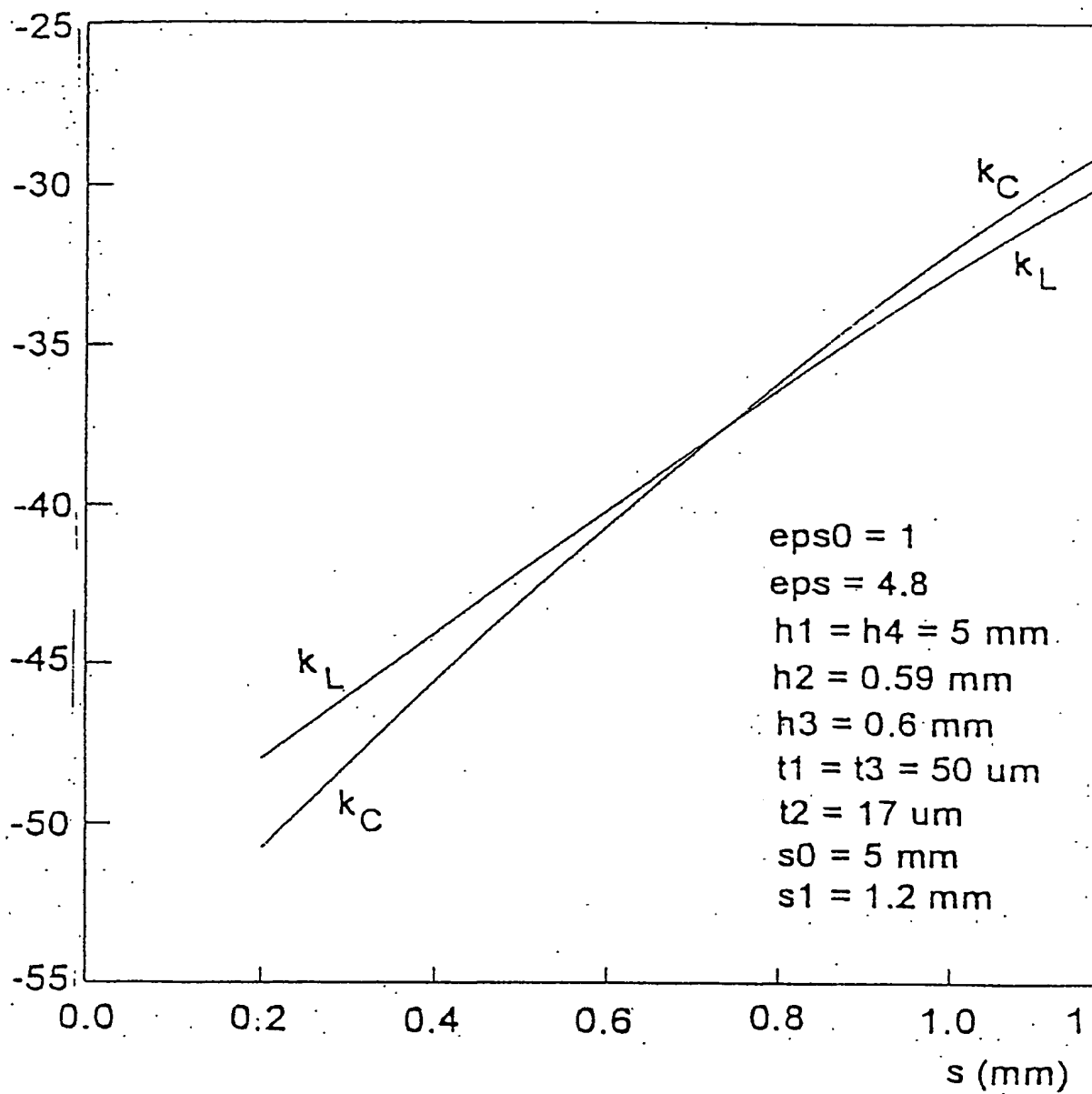h1 = h4 = 5 mm
h2 = 0.59 mm
h3 = 0.6 mm
t1 = t3 = 50 um
t2 = 17 um
s0 = 5 mm
s1 = 1.2 mm

Fig. 14 b

Fig. 14 c

Fig. 15